LAPP-EXP-2009-12
October 2009

Search for ν_τ appearance via neutrino oscillations in the ν_μ CNGS beam with the OPERA experiment

A. Zghiche

LAPP - Université de Savoie - CNRS/ IN2P3
BP. 110, F-74941 Annecy-le-Vieux Cedex, France

Presented at the 21ème Rencontres de Blois "Windows on the Universe",
Château de Blois (France), 21-26 June 2009

Search for ν_τ appearance via neutrino oscillations in the ν_μ CNGS beam with the OPERA experiment

A. Zghiche
LAPP, Universit de Savoie, CNRS/IN2P3, 9 Chemin de Bellevue, F-74941 Annecy-Le-Vieux, France

The OPERA neutrino detector in the underground Gran Sasso Laboratory (LNGS) is designed to realize the first detection of neutrino oscillations in the appearance mode through the study of $\nu_\mu \rightarrow \nu_\tau$ oscillations. The apparatus consists of an emulsion/lead target associated to electronic detectors and is placed in the high energy long-baseline CERN to LNGS beam (CNGS) 730 km away from the neutrino source. Runs with CNGS neutrinos were successfully carried out in 2007 and 2008 with the detector fully operational with its related facilities for the emulsion handling and analysis. After a brief description of the beam and of the experimental setup we report on the collection, reconstruction and analysis procedures of first samples of neutrino interaction events.

1 Introduction

Recent 'Solar' and 'atmospheric' neutrino experiments discovered that lepton flavour is not conserved, thus identifying the new physics responsible of this anomaly has become the aim of active calculations. Although observed flavour conversions could be produced by different mechanisms, simplicity suggests oscillations of massive neutrinos to explain the data, provided that mixing angles among the Standard Model neutrinos are sufficiently large. Present data strongly disfavor alternative exotic possibilities, such as neutrino decay or oscillations into extra 'sterile' neutrinos and show some hints for the characteristic features of oscillations.

Oscillations can be directly seen by precise reactor and long-baseline beam experiments, that are respectively testing the solar and atmospheric anomalies. In the case of the atmospheric neutrino sector, accelerator experiments can probe the same oscillation parameter region as atmospheric neutrino experiments. This is the case of the OPERA experiment dedicated to the first direct detection of $\nu_\mu \rightarrow \nu_\tau$ appearance, not yet observed, while being the most probable explanation of the atmospheric data.

The OPERA [1] experiment is located in the Gran Sasso underground laboratory (LNGS) in Italy. The detector developed by the OPERA international collaboration is designed to search for ν_τ appearance in the high energy ν_μ CERN to Gran Sasso (CNGS) beam, 730 km downstream of the neutrino source. The ν_τ direct appearance search is based on the observation of leptonic and hadronic τ decays in the ν_τ charge current interaction (CC) events. Because of the weak neutrino cross section and the τ short lifetime, the OPERA detector [2] must combine a huge mass with a high spatial resolution. Both requirements are fulfilled using nuclear emulsions combined with lead plates and assembled into detector units called "bricks".

The CNGS ν_μ beam is designed to provide 4.5×10^{19} proton-on-target/year (p.o.t./y) with a running time of 200 days per year. The beam parameters have been tuned to optimize the number of ν_τ charged current interactions in the OPERA detector. Thus, the average neutrino

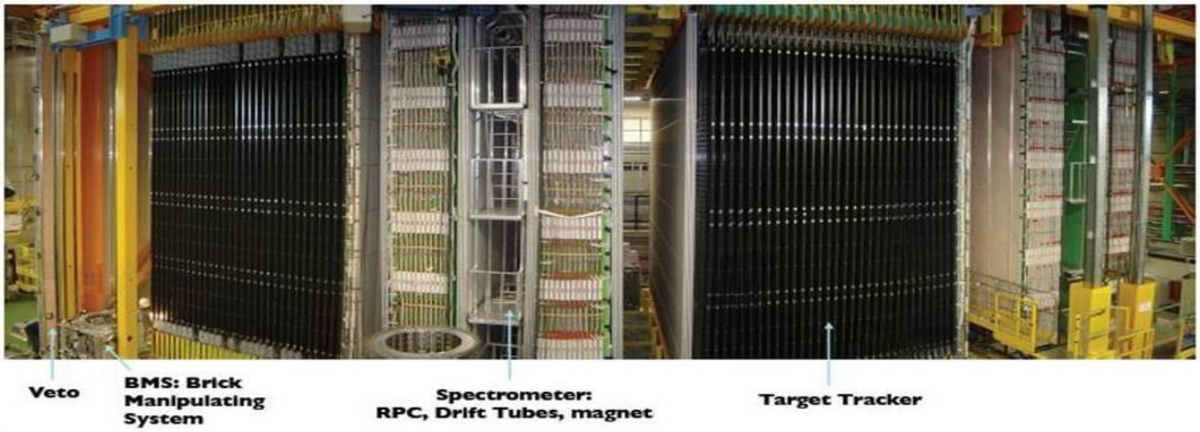

Figure 1: View of the OPERA detector

energy is $< E >= 17$ GeV for an almost pure ν_μ beam only with a small contamination of $\bar{\nu}_\mu(4\%)$ and of ν_e and $\bar{\nu}_e$(less than 1%). The average L/E ratio is 43 km/GeV, far from the oscillation maximum, due to the high energy required for ν_τ appearance. In 5 years of data taking, OPERA foresees to observe 10 to 15 ν_τ events from oscillation at full mixing in the range $2.5 \times 10^{-3} < \Delta m^2 < 3.0 \times 10^{-3}$ eV^2, with a total background of 0.75 events.

2 The OPERA Detector

OPERA is a hybrid detector (Figure 1) made of two identical Super Modules (SM) each consisting of a target section of about 625 tons made of emulsion/lead bricks, of a scintillator tracker detector (TT) needed to trigger the read-out and localize neutrino interactions within the target, and of a muon spectrometer. The latter, made of two parts located downstream of each SM, provides the charge and momentum informations of the penetrating tracks. Each spectrometer is equipped with RPC bakelite chambers and High Precision Tracker (HPT) composed of drift-tubes. The spectrometer reduces the charge confusion to less than 0.3%, gives a muon momentum measurement better than 20% for a momentum less than 50 GeV/c and reaches a muon identification efficiency of 95%. The rejection of the charged particles originating from outside the target fiducial region coming from neutrino interactions in the surrounding rock material is provided by a large size anti-coincidence detector (VETO), made of two glass RPC planes mounted in front of the first part of the target.

The target section is composed of 29 walls. Each one is made of an X-Y double layered wall of scintillator strips (the TT) and a vertical supporting steel structure that contains the basic target detector units called Emulsion Cloud Chambers (ECC) bricks. A total of 150036 ECC bricks with a total mass of 1.25 ktons have been produced to make the OPERA target. Each ECC brick is a sequence of 57 emulsion films interleaved with 56 (1 mm thick) lead plates. An emulsion film is composed of a pair of 44 μm thick emulsion layers deposited on a 205 μm plastic base. Downstream of each brick (Figure 2), an emulsion film doublet called Changeable Sheet (CS) is attached in a separate enveloppe. The CS doublet can be detached from the brick for analysis to confirm and locate the tracks produced in the electronic detectors by neutrino interactions. The CS doublet is the interface between the ECC brick and the electronic detector. The ECC bricks have been assembled underground at an average rate of 700 per day by a dedicated fully automated Brick Assembly Machine (BAM).

The detector is equipped with an automatic machine, the Brick Manipulator System (BMS) that achieved the entire brick insertion and will perform the extraction of bricks from the detector during the foreseen data taking period. In order to cope with the analysis of the large number

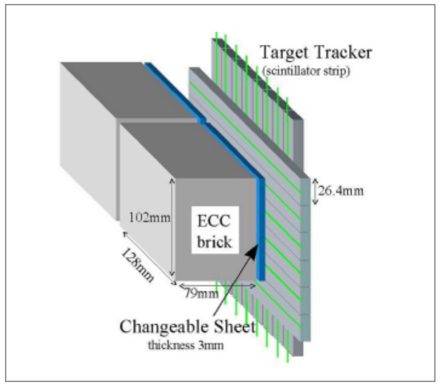

Figure 2: Schematic view of two bricks with their Changeable Sheets and target tracker planes.

of emulsion sheets related to neutrino interactions, large automated facilities are used for the handling, the development and the scanning of the emulsion films. For the latter task, two new generation computer driven fast automatic optical microscopes have been developed: the European Scanning System ESS [3] and the Japanese S-UTS [4]. While the implementation differs in both the hardware and software architectures, the two systems have comparable performances ensuring a scanning speed up to 20 cm^2/h, and a spatial and angular resolution of the order of $1\mu m$ and 1 mrad, respectively.

3 The OPERA Event Selection

For a given event, the electronic detectors are used to compute a probability map of the location of the interaction brick. The brick with the highest probability is extracted by the BMS. Then the CS doublet is detached from the brick and developed in the underground facility. The two emulsion films are scanned by using fast automated microscopes. If the track candidates found on the CS doublet match with the electronic data then the brick is exposed for 12 hours to cosmic rays in order to provide the film-to-film alignment in the brick. Subsequently the brick is developed in an automated facility and sent to the scanning laboratories either in Europe (ESS) or in Japan (S-UTS). The vertex finding strategy consists in following back, film by film, the tracks found on the CS doublet until the tracks stop inside the brick. To confirm the stopping track, an area scan of several mm^2 around the stopping point of the tracks is performed for 5 films upstream and downstream. Then an interaction vertex can be reconstructed and a topology compatible with the decay of a τ lepton is sought.

4 Run Status and Real Data Events

After a short commissioning run in 2006, the CNGS operation started on September 2007 at rather low intensity with 40% of the total OPERA target mass. Due to the operational problems of the CNGS, the physics run lasted only a few days. During this run 0.082×10^{19} protons on target (p.o.t.) were accumulated and 465 events were recorded, but only 35 in the target region. The other events originated in the spectrometers, the supporting structures, the rock surrounding the cavern and the hall structure. From June to November 2008, 1.782×10^{19} p.o.t. were delivered by the CNGS. OPERA collected 10100 events with 1663 interactions in the target region. This number is compatible with the MC (Monte Carlo) simulation prediction of 1723 interactions. All electronic detectors were operational and the live time of the data acquisition system exceeded 99%. For the events classified as CC interactions in the target the muon momentum and the muon angle in the vertical (y-x) plane with respect to the horizontal

(z) axis distributions were found in agreement with the MC simulation expectation [5]. By mid-june 2009, 1019 bricks have been developed and around 746 events have been located. The brick finding efficiency value is around 80%. The vertex finding efficiency in the selected bricks for CC events is between 84-95 % while a value of 93% is predicted by the MC simulation. For NC events, the efficiency ranges between 70 and 91 % while the MC simulation prediction is 81%. In a sample of 550 ν_μ CC interactions and among the located events, 8 events show a charm-like decay topology in agreement with the MC simulation predicted value of 10. Because charm decays exhibit the same topology as ν_τ decays and because they are a potential source of background if the muon at the primary vertex is not identified, Charm production and decay events constitute the best calibration channel for the OPERA detector. A charm-like topology is shown in Figure 3 where a track exibits a decay-kink.

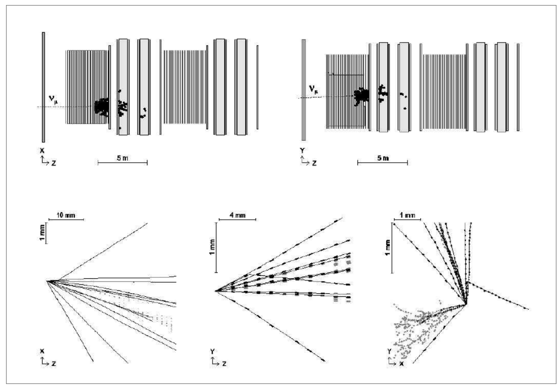

Figure 3: Display of the OPERA electronic detector of a ν_μ charged current interaction with a charm like topology (top panel). The emulsion reconstruction is shown in the bottom panels where the charm-like topology is seen with a kink: top view (bottom left), side view (bottom center), frontal view (bottom right). The dots in the lower panel are due to an electromagnetic shower.

5 Conclusion

During the 2008 CNGS run all the electronic detectors performed well. The OPERA strategy has been validated and the vertex location was successfully accomplished for CC and NC events. In the analyzed data sample of 550 ν_μ CC interactions, 8 events with a charm-like topology were found. This is in agreement with the expectations and shows the success of combining the topological and kinematical analyses. The 2008 run constitutes an important milestone for the OPERA experiment. For the 2009 run, around 3.5×10^{19} p.o.t. are foreseen to be acquired. The integrated statistics would be sufficient to expect the observation of two events and give a precise estimation of detector efficiency, background and sensitivity.

References

1. M. Guler *et al.*, The OPERA Collaboration, Experimental Proposal, CERN 98-02, INFN/AE-98/05 (1998).
2. OPERA Collaboration, R. Acquafredda *et al.*, *JINST* **4** P04018 (2009).
3. L. Arrabito *et al.*, *Nucl. Instrum. Meth.* **A** 568 (2006) 578; L. Arrabito *et al.*, *JINST* **2** P05004 (2007); Armenise *et al.*, *Nucl. Instrum. Meth.* **A** 551 (2005) 261.
4. T. Nakano, Automatic analysis of nuclear emulsion, Ph.D. Thesis, Nagoya University, Japan (1997).
5. OPERA Collaboration, N. Agafonova *et al.*, *JINST* **4** P06020 (2009).